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ABSTRACT

Written as part of a series for the Science Council of Canada, this publication focuses on elementary and secondary school science education as it effects students in general and those pursuing engineering and technical careers in particular. Section one examines post-Sputnik science education and claims that an overly narrow emphasis on pure science has resulted in decreased science enrollment and has failed to meet the needs of general students, students seeking careers in the applied sciences, and society. Section two differentiates among technology, engineering, and science. The final section suggests different approaches for teaching science and emphasizes the need to balance content with context indicating that science curricula must stress application, technology, and social implication. (DC)

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An Engineer's View of Science Education

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A Discussion Paper
by Donald A. George

Science Council of Canada

SE 036 383

AN ENGINEER'S VIEW OF SCIENCE EDUCATION

A Discussion Paper

by Donald A. George, P.Eng.

June 1981

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FOREWORD

This paper has been prepared for a study of Canadian science education being undertaken by the Science Council of Canada, under the direction of its Science and Education Committee. The study, which began in the spring of 1980, has three overall aims:

- to establish a documented basis for describing the present purposes and general characteristics of science teaching in Canadian schools;
- to conduct an historical analysis of science education in Canada;
- to stimulate active deliberation concerning future options for science education in Canada.

As this third aim suggests, the Science Council has no collective view on desirable directions for science education in Canada. It is seeking, however, to develop such a view and to this end is actively soliciting a diversity of opinions concerning possible directions. It is intended that these opinions, articulated in the form of discussion papers and disseminated as widely as possible, will prompt science educators and others to review current policies and practices. By sharing in these deliberations and at the same time conducting a a systematic inquiry into current and past policies and practices, the Science Council hopes to acquire a good understanding of the state and needs of science education in this country, and thereby make constructive recommendations for its improvement.

Two papers in this series have been published so far: *A Canadian Context for Science Education* by James Page, and *Science in Social Issues: Implications for Teaching* by Glen Aikenhead. Both authors have advanced arguments for the consideration of new goals for science education programs in Canadian schools.

In *An Engineer's View of Education*, Donald George makes this same argument from another perspective. Professor George has a background in engineering, both as a practising professional and as a university teacher. He views current trends in science education with concern, focussing on the preoccupation that science education has had on the discipline of science - the discovery and validation of knowledge - as distinct from engineering, which is the application of knowledge towards the solution of real problems. He believes it is the responsibility of professional science educators to develop and test reforms to science education. We hope this paper will stimulate discussion concerning the desirability and feasibility of such reforms.

It must be stressed that the views expressed in this discussion paper are those of the author, and not necessarily those of the Science Council or its Science and Education Committee. However, in publishing the paper, Council believes that a well-argued position has been set out, and that discussion among a wider audience can benefit both the study and Canadian science education in general.

James M. Gilmour,
Director of Research,
Science Council of Canada.

TWO DECADES AFTER SPUTNIK

Science education in our schools is a vital part of the preparation for the study and practice of engineering. It is also from the science taught in school that the attitudes of the general public to science, engineering and technology are formed and these attitudes, in turn, have a direct effect on public policies.

This paper focuses on these two aspects of science education in presenting an engineering viewpoint (or at least one engineer's viewpoint) of contemporary science education in Canadian schools. The writer is both a practising engineer and an educator.

Canada's wealth of physical resources has allowed us to live well in one of the world's most "developed" countries. But we do not develop our own land; rather, we rely on others to exploit our resources and we are paid a fee for our acquiescence. We benefit in this way from the world's technology and science, and devote our energies to other pursuits; we seem almost deliberately to atrophy our indigenous technological resources.[1] *Science education in Canada plays a special role in this policy of perpetual underdevelopment.*

Just as war is too important to be left to generals, science is too important to be left to scientists. But in the 1950s, inspired by the new challenges and directions created by Sputnik, decisions were made to reform science education, and the nature of those reforms was left to the science establishment. Others who were affected by these changes, such as engineers, were not consulted.

Two decades later science education is in disarray, although scientists, who have their own views on what constitutes science education, are not entirely to blame. Physicists, chemists, biologists and other scientists, by the virtue of their specialization, do not necessarily have a comprehensive view of science.

Although the reforms instituted during this time have benefited many students who have the inclination and ability to specialize in science, students in other disciplines have suffered from a decreasing exposure to a general, meaningful, science education. As a result, scientists grow more isolated from the public, and general ignorance of science and technology increases.

The first casualty of this situation has been science itself. While science education has become more specialized and the proportion of students studying science has dropped, the benefits of science and technology have become less and less self-evident and public support for science has declined. Prominent Canadian clergy claim that the "God of Science" is dead and look for a return of the "God of the Bible."[2] To the dismay of many scientists, the support for scientific research that still exists is based solely on potential economic returns.

The scientific establishment itself has not benefited, in the long run, from the undeniable improvements in the quality of science education, because they have been accompanied by decreased enrolments in high school science classes, which have in turn affected the number of students with the necessary prerequisites for post-secondary science education. In the United States, recognition of this same trend has led recently to a special report for the President on the problem.[3]

Another factor is that young people increasingly elect educational programs with clear-cut career prospects. Enrolments in engineering and technology are soaring, in sharp contrast to those in

the pure sciences.[4] When the flow of students from high school to universities and colleges peaks and then falls, as it soon will, students studying pure science may become rare indeed and projections about the future number of students for technology, engineering and science courses is disturbing, even frightening. Even engineering and technology programs will not maintain their enrolments. North America, and Canada in particular, face increased technological competition, thus the availability of qualified people is of paramount concern.

The ever-narrowing base of science education is reflected in an after-dinner speech delivered by Lester B. Pearson, a former prime minister of Canada. He talked about his problems with a mandatory mathematics course taken while studying arts at the University of Toronto. It was not so much that he found the course difficult, but that he thought it pointless. The majority of people are not inclined towards quantitative analysis. Their mode of thought, like Mr. Pearson's, is qualitative. However, the teaching of science by those with scientific backgounds is inevitably quantitative, and unless special efforts are made people who think qualitatively are effectively deprived of a science education.

A paradox of science education emerges. On the one hand, science taught by teachers who themselves were not attracted to it, and perhaps came to dislike it, cannot be stimulating. On the other, science taught conventionally by well-trained science teachers must be far less than satisfying for those not scientifically inclined. Courses that minimize the quantitative approach exist, but are described perjoratively in science circles by the adjective "soft." The courses and those who teach them are held in much lower scientific esteem than their "hard" counterparts. It is not surprising that the people with a "hard" science orientation, given the money and the mandate to improve science education, made the reforms they did.

As rivalry in space accomplishments intensified after Sputnik, science in the school system became increasingly "scientific" - more basic and less technological. Changes to the mathematics program attracted the most attention, because parents found they could no longer help their children with homework. But all science curricula changed in similar ways. The new courses concentrated on pure rather than applied science, and were also more abstract.

As the reforms in science education were being instituted, other changes were taking place in the educational system. The curriculum was no longer compulsory, and students were permitted to choose most of their courses. In Ontario the credit (or blame) for this is assigned to the Hall-Dennis Report[5], but the trend was country-wide. Given the opportunity, most students chose not to study science.

An important reason was the narrowed base of science education, resulting, ironically, from the decision to emphasize science teaching. An apparent solution is simply to reimpose compulsory science courses; enrolments would recover instantly. Perhaps some people would then assume that the problem was solved, but this would be an illusion. As Mr. Pearson pointed out, probably all he gained from his compulsory mathematics course was a life-long hatred of calculus. With current student and parental attitudes towards science education, some science courses may have to be mandatory, but science teaching itself must also change.

Engineering students have another view of contemporary science education. An engineer's first formal exposure to science takes place in the primary school. Scientific knowledge is accumulated through high school and the first years of an engineering program at university, where potential engineers are compelled to follow courses designed for those interested in careers in pure science. Because of this, many potential engineers are lost along the way. Those students who wish to become engineers will achieve their goal only if they have

a marked affinity for science or great determination to succeed in science courses they may not enjoy. But many others will not make it, despite the fact that the field of engineering is very broad and people with a wide range of talents are needed to fill the variety of positions available. They will give up or go off in other directions.

Some people defend this situation on the grounds that those who drop out of engineering lacked the necessary stamina, but such a response ignores the many pressures of the educational system on today's young people. The attitude that only those students who show an aptitude for the pure sciences should become engineers is also misguided, and would be acceptable only if the courses in pure sciences offered in our schools were necessary for engineering study. In fact, a curriculum oriented towards applied science would be far more relevant and attractive not only to would-be engineers but to other students as well.

The requirements for science and mathematics in the backgound of an engineer varies. There are research engineers who are pure scientists, whereas some practitioners must rely entirely on experience and judgement. The mix of arts and science in the practice of engineering is but one of the variables that change markedly from one engineering job to another and from one engineer to another. It is questionable if a single path in science education is sound, especially if it is biased towards the education of pure scientists.

Obviously, the eventual career of a potential engineer cannot be determined beforehand, so a basic and substantial minimum proficiency in science and mathematics must be attained. But is it provided by the school science programs developed over the last two decades? Do the reforms, made without regard for their impact on engineering education, satisfy the needs? Apparently not, because there is a scarcity of young people prepared to undertake careers in engineering, technology and science. Maintaining our present level of economic and

social advantages, much less raising it, demands a great many qualified people. Unfortunately, this point is not well appreciated by the general public or our political leaders. As Walter Light has noted:[6]

> "It is very apparent that Canadians - inside and outside of government - do not, or do not want to, understand that tomorrow's jobs, their continued high standard of living, the health of the economy and the real future security of the country rests upon the success or failure of our technologies, and on our skill to create and develop them faster and better than other countries."

An opposing argument - that there is an over-supply of one kind of specialist or another, or of "overeducated" people generally - exists, but one must wonder why. The unemployment rate of university graduates in general, and engineering graduates in particular is well below that of the rest of their age group.

Claims that engineers are often under-employed, accompanied by implications that too many are being graduated, also surface from time to time. At the same time our society seems content to graduate large numbers of students from academic disciplines that contribute little to our economic or physical wellbeing. If potentially productive people appear to be under-utilized in some organizations, then the management of those organizations must be suspect, or the individual's capabilities are being overrated. It makes no sense to underutilize and undereducate potentially productive Canadians, but that is in effect sometimes advocated, even in engineering circles. A small minority of engineers probably still exists that equates a decreased supply of engineering graduates with increased salaries for themselves, but if Canada's potential is to be realized our continuing need for all the highly trained and skilled people we can produce must be met.

The decline in enrolments can be attributed to the policy of allowing students to choose their courses, but I have argued that

imposing courses is not necessarily a cure, for the greatest effect of compulsory science may be an alienation from science. The science curriculum itself must be examined, and the most effective way to determine course content, short of returning to school and doing it all again, is to examine textbooks. This turned out to be a rather startling exercise, for there has been a dramatic change over the last several decades. For example, a contemporary physics text explains basic mechnical laws well and imparts the information with fine illustrations and an elegant use of colour and typography. By comparison the textbooks of yesteryear look pallid and unimaginative.

Today's textbooks look better, but their orientation is their abstract, mathematical orientation. No effort is made to explain why the diagrams and equations of basic mechanics are included. The author knows why the topic is included - all scientists know that mechanics is an important branch of science - but does the student know? And if he or she does not, then why should the student be interested in this apparently arcane subject?

The older texts, by contrast, considered that the orientation and motivation of the student were of primary importance. Only after the industrial, social, and economic basis of the topic was established did texts go on to the theoretical scientific principles, and then return to the application of those principles. At that point the application would be specific and the student could then understand the use of science in the practical world. But in 1980 the applications, if mentioned at all, relate to yet more science, such as experimental measurements or new phenomena. There is seldom a real example of the application of the principles of the physical sciences outside the physical sciences themselves.

It is not only the textbooks that reveal the present nature of science education in our schools. An Ontario curriculum guideline for intermediate division science lists 26 reasons why a student might

choose to study science.[7] Not one relates to technology, engineering, the use of science, or of the economic or social benefits of science, except in an occasional backhanded and negative sense. To quote:

> "Science lets you look in your rear-view mirror and makes you wonder how your forebears ever got along without television sets, cars, radios, telephones, antibiotics, hand calculators, electric blankets and automatic dishwashers. Or were they so unfortunate?"

and

> "Science may influence your attitude towards a personal respect for animals and plants, care of scientific apparatus, conservation of energy resources, and a concern for such problems as hygiene, overpopulation, disease, drugs, and weapons of warfare."

More typical of the list, however, is:

> "Science can help you grow intellectually, because it lures you to guess and question, to wonder and grope, and to try to fathom the depths of simple mysteries."

To emphasize further the imbalance between pure science and technology, one need only turn a few more pages of the same guideline.[8] Four curriculum emphases are discussed: scientific literacy; science, technology and decisions; scientific process; and the structure of science. Technology and the application of science occupies but one-half of one of the four possible emphases. One reads also that:

> "The student understands that science differs from technology as knowledge-seeking differs from practical problem-solving."[9]

Thus it is clear that in Ontario at least the science of the schools is pure science.

This bias is fine for the scientist whose interest is in science for its own sake and it may succeed with the student who is naturally interested in and capable of easily understanding the principles of science, but it does little for the vast majority of students. Instead of the vital, important force that it is, science is presented as abstract, remote and, even worse, boring and difficult.

If the only objective of science teaching is to produce scientists then this approach may be valid. The cost, however, is the creation of anti-science attitudes in the typical student and the loss of many potential science students. As almost all engineering students have a strong orientation towards the practical, this theoretical approach can hardly be appealing. Many students will therefore make very early decisions to opt out of science that will later preclude the study of engineering and technology.

Careers in engineering and technology can be particularly satisfying, secure and financially rewarding, and often lead to careers of still broader scope. In this context, there is some irony in the continuing low participation of young women in science courses which, in turn, excludes them from so many of these more satisfying occupations. Women are said to be more pragmatic and practical than men, so the study of science as it is taught today is particularly unappealing to them. Yet these same attributes are significantly appropriate for the practice of engineering.

Not only the prospective engineer or technologist is poorly served by current science education. Scientific knowledge in the general populace has also declined. There should be common concern between those involved with general education and those with engineering education. And there should be concern among those who would like Canada to formulate an industrial and technological policy that goes beyond the exploitation of the country's natural resources. But technologically and scientifically illiterate people cannot debate these

issues. The Symons Report[10] of the Commission on Canadian Studies concluded that the majority of the public, even of university students, are scientifically illiterate, and the problem is worsening.[11]

II TECHNOLOGY, SCIENCE AND SOCIETY

There is little widespread concern about contemporary science education. Because the resources of our engineering schools have not kept pace with enrolment, university engineering professors have more students than they can handle and they may lack a true perspective about the low overall number of graduates that Canada is producing each year. Also, because these professors may be biased towards the scientifically and mathematically talented students who, like themselves, will probably become researchers, they are not troubled by a curriculum that favours a theoretical, rather than a practical approach to science, and which discourages many talented students from becoming engineers. Scientists themselves are concerned about the low enrolment in science disciplines, but may be conditioned not to see the reasons. The non-science fraternity knows little about the situation and is not particularly concerned. "Because little is known, less will be known" becomes a self-fulfilling prophesy.

The sporadic public debate about science education that does occur between scientists and the public has little meaning because the debaters know so little or so much of science that they do not share a common language. Science, along with technology and engineering, is a word central to any debate on education that deals, one way or the other, with technology - the primary force in the western world in this

century. The impact of technology is all-pervasive in our society, but understood by all too few. As Carl Sagan says:

> "We have a society which is built on science and technology and which uses science in every one of the interstices of national life, and in which the public, the executive and the judiciary have little understanding of what science is about. That is a clear disaster signal. It has to be suicidal."[1]

The meaning of the words *technology, engineering,* and *science* are clouded. More often than not they are used inappropriately or even incorrectly. In the strict context of this paper, for example, the term science education refers to the teaching of physics, chemistry and biology in the primary and secondary schools. Those are classed as the science subjects; yet this is part of the problem. Teaching and learning the basics of these particular physical and natural sciences is only one aspect of what science education should be. The word "science" has some specific narrow definitions, but also some much broader meanings. The latter must prevail in any discussion of science education and must also be the focus of science education.

Another example of confusion is found in a recent flurry of newspaper articles pointing out that the Ottawa-Carleton region is developing a strong industrial orientation in so-called "high technology" and that this has resulted in a shortage of qualified people to fill positions. The media transformed the situation into a shortage of "technologists" and demands were made for increased provincial support for their education in the colleges and technological institutes. However, the shortage of technologists is only part of the picture; the high technology industry also requires engineers, scientists, and other specialized workers. Equally serious educational problems exist for them too. Unfortunately, media misinterpretation of the word technology in "high technology" distorted the direction of public attention so that only a part of the problem received attention.

Thus we have a graphic example of how a problem involving a number of very different factors has been publicized in terms of only

one, because of ignorance of the meaning of the words technology, science and engineering. People who work with technology have a wide range of educational backgrounds, including the PhD engineer, the technologist, the skilled tradesman and the production worker. All require a basic science education; a weakness in science education, therefore, has far-reaching effects.

A further example of our problem with the language of science and technology is found in the need felt by Canada's engineering deans to lobby for the inclusion of "engineering" with "science" in the title of the federal government's new research granting agency, the Natural Science and Engineering Research Council of Canada. In their (successful) effort the deans were fighting on two fronts: for the widening of the general interpretation of the role of a "science research council" and for the council's support of science and technology as opposed to just science.

It seems appropriate at this point to examine some definitions of science, technology and engineering. A standard definition of science is Webster's:

> "2. Any branch or department of systematized knowledge considered as a distinct field of investigation or object of study; as, biology is a science; the science of astronomy or of mind."
>
> "3. A branch of learning; a science; esp. a science such as grammar, logic, or mathematics..."[2]

This is further tightened to:

> "A branch of study which is concerned with observation and classification of facts, esp. with the establishment (and, strictly, the quantitative formulation) of verifiable general laws, chiefly by induction and hypothesis; as, the biological, historical, and mathematical sciences."[3]

The Oxford dictionary makes the same point more emphatically:

> "5b. In modern usage, often treated as synonymous with 'Natural and Physical Science', and thus restricted to those

> branches of study that relate to the phenomena of the material universe and their laws, sometimes with implied exclusion of pure mathematics."[4]

Thus we have this word, science, which can be restricted to a narrow definition referring only to the physical and biological sciences. In Canada unfortunately, this narrow sense appears to prevail and trends in science education in the primary and secondary schools have reinforced a limited appreciation of the scope and nature of science.

A broader definition of science is found in the New Columbia Encyclopedia:

> "For many the term science refers to the organized body of knowledge concerning the physical world, both animate and inanimate, but a proper definition would have to include the attitudes and methods through which this body of knowledge is formed; thus, science is both a particular kind of activity and also the result of that activity.... Science may be roughly divided into the natural sciences and the social sciences.... The natural sciences are divided into the physical sciences, the earth sciences and the life sciences. Mathematics is also considered one of the physical sciences.... All of these areas of study might be called pure sciences, in contrast with the applied or engineering sciences, i.e. technology, which is concerned with the practical application of scientific activity."[5]

Which meaning is to be taken: the narrow physical-sciences sense or this broad description? John Diefenbaker hailed as a great scientific achievement the launching of Canada's first satellite, but it was very much an engineering accomplishment. What did he mean by "scientific" achievement and how was his statement interpreted?

The other two pivotal words: "engineering" and "technology," pose fewer problems. Webster's defines technology as:

> "1. industrial science, the science or systematic knowledge of the industrial arts, esp. of the more important manufactures as spinning, weaving, metallurgy, etc."
> "3. Any practical art utilizing scientific knowledge, as horticulture or medicine; applied science contrasted with pure science."

and engineering as

> "... the art and science by which the properties of matter and the sources of power in nature are made useful to man in structures, machines and manufactured products; the occupation and work of a professional engineer..."[6]

It is evident from this definition that the professional competence of the engineer is very much based on an understanding of a broad range of the sciences - pure and applied - together with his or her command of the engineering arts.[7]

Engineering however, is not what it is generally assumed to be: the application of the physical sciences to practical ends. One way to appreciate this is to distinguish between the science that observes, measures, and describes naturally occurring phenomena and the science that concerns man-made phenomena. Communication and information theory, for example, have been developed in this century to describe the laws that govern the transmission and reception of signals. Similarly, the electrical and mechanical sciences have developed new knowledge of the nature of circuits, systems, and machines, which have their main significance in the work of engineers. These "sciences of the artificial," or engineering sciences, are a relatively new factor in science. Even their existence is unknown to the vast majority of people whose science education was limited to physics, mathematics, chemistry, and biology.

Yet young students are taught physics, chemistry, and biology as abstract, self-significant sciences which understandably come to represent the whole of science in their minds. This impression is reinforced later in their schooling when these branches of science become compartmentalized into clearly distinct courses taught by specialists. By this time the majority of students elect not to study science further, so these early concepts remain throughout their lives. Engineering and the work of engineers remains obscure. At best, engineers are thought to apply science (physics, chemistry, biology) and mathematics to some practical ends. Technology is perhaps seen as

the result of this application of science, and perhaps thought to be dangerous too. How levers and pulleys, force and energy relate to technology and to everyday life remains a mystery to be absorbed, presumably, through the experiences of life.

Thus, the typical student ends his secondary education with a distorted view of science and virtually no concept of engineering and technology. And yet this is the students' preparation for the 21st century. It is not even appropriate for the 20th century!

The next stages of the educational system are no better. The college or institute of technology has no choice but to assume that the student's basic education is complete, and proceed with his or her training for a particular occupation. The university makes the same assumption, and launches into specialized education. Students stay close to their chosen discipline, venturing timorously into contiguous zones but seldom into a distant area in another faculty. Arts students do not study science and science students do not study arts. The smorgasbord curriculum allows students to reinforce their conditioned biases against science courses (or against arts courses if they are in science). Departmental regulations aid and abet this bias.

By this time selective ignorance is institutionalized and a life-long pattern has been established, but curiously this curriculum and process are thought to be a basic, fundamental, core, general education and to have first priority. Even in current plans to rationalize university programs in Ontario, the undergraduate sciences, humanities, and social sciences are exempted.[8] Presumably the public purse will provide whatever is needed for these programs (and they are the larger part of the budget). At the same time the professional programs, graduating students who will contribute to our economic well-being, will be subjected to the limitations and constraints of the typical Ontario university system planning process in the name of conserving resources and limiting demands on the taxpayer. Both the educational and economic sense of this escapes me.

Canada's engineering faculties require their students to study general science, mathematics, economics, administrative science, humanities and social sciences. The intent is practical, for the engineer must appreciate the social, economic and ecological environment in order to practise his or her profession. This is in sharp contrast to the educational requirements of students taking a general arts education. The universities, as the custodians of higher education, are content to let their arts graduates go forth into the world enjoying both the benefits and drawbacks of technology, in ignorance of the basic principles of engineering, science, and technology.

Without technology we would revert to the agricultural society of the last century which some purport to prefer but few have embraced, and most do not want. If many of the profound problems facing us, such as the crisis over energy which now strains our national unity, or our declining economic and industrial fortunes, or pollution, have arisen from technological development, their solutions nevertheless lie in further advances in technology. But the debate on nuclear energy, policy and strategy, to take one example, becomes hysterical, fed by unfounded notions about nuclear science and engineering. It is hard to find a path between those who would forbid all nuclear development and those who would charge ahead, regardless of the consequences.

To discover the solutions to today's problems, we must make critical decisions, we must invest today for tomorrow's well-being, and we must have concerned, informed citizens. That we do not is the great disgrace of an educational system that is content to leave its graduates woefully innocent of science and technology. We have allowed many technological problems to accumulate, illustrating our general ignorance of the interactions of technology with our adopted life style, and the pressing need to eradicate scientific illiteracy.

A final point must be made about the importance of educating young Canadians to be aware of technology even if they do not pursue technological careers. The assertion made to the Symons Commission,

"... that to speak of Canadian science or of Canadian engineering is inappropriate; that science and technology transcend all national boundaries, and consequently cannot be national in character,"[9] does not conform with reality. In fact, the Commission identified the "national or cultural dimension" in terms of the impact of science and technology on society and our lack of a perceived scientific heritage.[10] They also listed an impressive and depressing catalogue of topics virtually unique to Canada that had suffered almost total neglect by science.[11]

Yet the Commission, by acknowledging that "science is international" implicitly accepted a limited definition of science which neglected the nature of technology. The basic laws of science are universal, but the applications of science and technology are intensely nationalistic. To our great detriment, this escapes notice in science education and in our institutions of higher education. From beginning to end, the bias is towards a universal science in which Canada's role is minor and unimportant. In fact, the development of science and technology in the Canadian context is critical to national survival. Appreciation of this is difficult for people schooled in the single, simple theme of pure science.

III SOME OPTIONS IN SCIENCE EDUCATION

The term "scientific illiteracy" as I have used it implies science in its all-encompassing sense and so includes technology. Perhaps "technological illiteracy" would be a better term, since the impact of science on our lives is felt through technology rather than directly through pure science. Because science, correctly defined, includes technology rather than the converse, and because the methods and philosophy of science are critical tools to apply to understanding the social and ecological consequences of technology, I have chosen to stress science. But this does not mean science as it is viewed by our schools. Science is not just physics, chemistry, biology, and perhaps mathematics.

The eminent American engineering educator John G. Truxal has posed two questions to illustrate two objectives of a reformed approach to science education in the schools:

> "Question 1: To minimize gas consumption, how long should you let your car warm up before driving on a cold winter morning?
> Question 2: To save gas, the federal government has two choices:
> (1) Improve subways and buses to increase ridership.
> (2) Use money to encourage commuters to buy cars that get better mileage.
> We are now using (1) and trying to double the ridership by a

> large commitment of federal money to mass transit. To save the same amount of gas, how much would we need to increase the gas mileage of cars used in commuting?"[1]

The first question has the reasonable and practical answer of 30 seconds; the second has the amazing answer of 0.2 miles per gallon. His two objectives, which are well demonstrated in the example, are to give students an understanding of how to respond to our technological environment and of how to participate in political decisions. A science education that directed students towards such questions would be a reorientation of the present approach to emphasize the relevance of science and technology. It would remove science from the abstract and introduce significant elements of engineering and technology into the schools.

A suitable approach would begin by illustrating the significance of science in social, practical terms. For example, mechanics could take on a new significance for young people, as it explains how a car works and what happens in collisions. When, through application, the requisite theory had been developed, attention could turn to the broader implications of science and technology.

A particular example of this is found in the Grey-Bruce Separate School Board (Ontario) where "measurement, an expectation for mathematics...is taught <u>through</u> energy with great success."[2] [Emphasis is the author's.]

Another alternative would be to give courses in technology, presumably in addition to regular science subjects. Technology does not, as conventional wisdom has it, necessarily follow science but often leads it. Although application invariably follows advances in pure science, science is frequently challenged to explain technological innovations. While the processes of experimentation are a critical part of technological advancement (as they are of scientific advancement) they do not necessarily require a scientific understanding of the physical processes involved.

The danger with basing general education on this approach is that it might produce superficially knowledgeable but basically ignorant citizens. Moreover, there would be no means of recognizing that our accumulated scientific and engineering knowledge is often insufficient to answer all the problems posed by its application.

From the particular standpoint of engineering education, technological preparation in the schools would not, by itself, be sufficient. An engineer is distinct from the technologist in several ways. One of the most important is the strong scientific basis of his or her knowledge of the engineering arts and sciences.

The principal reason for rejecting the present approach and reforms of the kind just discussed is their lack of balance. Orpwood and Roberts[3] have modelled six possible objectives for science education. Students should be able to:

1. apply science;
2. appreciate its social impacts;
3. appreciate its application to technology;
4. understand Canadian issues in science;
5. understand Canadian contributions to science; and
6. comprehend the role of science in personal and political choices and decisions.

In this they were addressing the context of science education, not its content. The implication is that a better balance between content and context is needed.

To achieve balance is critical; balance not only in the proportion of time devoted to the various topics, but also in the approach to the teaching of science. Rather than courses devoted to physics, chemistry, biology and mathematics as pure sciences, we need curricula that stress - in both content and context - the broader themes of science and technology. Through emphasis on the application

and practical value of science, its appeal can be increased for the benefit of all students, not only potential engineers, technologists, and scientists. Such an emphasis would introduce the students to engineering and technology as well as to the pure sciences and to newer areas such as computing sciences.

The computing sciences are an excellent example of combining mathematics with a practical skill and an understanding of the impact and importance of a modern technology. A goal for all high school graduates should be rudimentary programming ability and an understanding of what computers really do. Many prevalent myths would be destroyed in the process.

It cannot be assumed that these suggestions for changes in the high school curriculum will be easy. A major reorientation of the kind I am suggesting will take time, energy, and talent on the part of both students and teachers. But it is vital that the task be undertaken, otherwise Canadians will become orphans in the high-technology world of the 21st century.

It is critical also that the courses and texts recognize and highlight the Canadian nature of relevant technology, our successes and our failures. It cannot be over-emphasized that while the laws of nature are universal, the application of science and technology is national and regional.

IV SUMMARY

My approach to the state of science education in Canada's schools has been from the standpoint of an engineer and an engineering educator. I have been concerned with the effect of primary and secondary education on students who will become engineers, technologists and technicians, rather than on those pursuing post-secondary studies in the physical, biological or mathematical sciences. Students wishing to pursue technological careers are principally concerned with applied science, but the latest reforms of science education in the early 1960s emphasized the pure sciences. Such an approach is inappropriate not only for these students but also for that majority of students who will not be focusing on science or technology. Thus my concern includes the scientific knowledge of the general public.

If Canada is to maintain its economic and social vitality in the 21st century we cannot afford scientifically or technologically illiterate citizens. Yet the present nature of science education is forcing us to accept such handicaps. Even informed public debate is not possible because of the general indifference and ignorance about the nature of technology and its social effects. The very words technology, engineering, and science have different meanings for different people in different contexts.

Comparison of school texts attests to the enhancement of pure science and the depreciation of technology over the past several decades. In the late 1950s and early 1960s a wave of "new" science and mathematics swept our schools. This intensified the emphasis on basic scientific principles, and was undoubtedly good for students who were innately interested and talented in science. Unfortunately, the difficulties for the majority of students who did not have these aptitudes were intensified. At about the same time, the prescribed curriculum, which allowed few options in course selection, was abandoned, so that by the early 1970s science enrolments in secondary schools were falling rapidly.

Paradoxically, both the general public and the science establishment have lost. Because they overwhelmingly elected not to enrol in science courses, young adults must by now be less knowledgeable about science and technology. Perhaps only the widespread fascination with science fiction sustains public support of science. At the other extreme, falling numbers of scientifically trained secondary school students and increased numbers of students entering engineering and technology programs have combined to bring about a major decline in university science enrolments.

This narrow approach to science, which emphasizes only basic scientific principles, is drying up both the supply of young scientists and public appreciation of and support for science and technology. At the same time, many students with more modest but still appreciable scientific talents are not being encouraged to find careers in the broad spectrum of science and technology. For example, simply providing more resources for university and college programs to obtain "high technology" manpower programs is not the answer. The problem is deeper: it begins in our elementary and secondary schools.

I conclude by arguing for curricular reform that will develop science programs with a strong orientation towards application, tech-

nology, and social implications. It is imperative to demonstrate that science and technology are critical to Canada and that appropriate science and technology are strongly and characteristically Canadian in nature.

This will not be an easy task, and I do not put forward remedies, but simply argue for a general direction. It is clear that we have a national problem of long duration and critical importance. Its resolution demands that educators and practitioners in technology, engineering and science overcome their entrenched differences. A meeting of minds and the formulation of common goals and objectives are urgently needed.

Failure will perpetuate our existing ignorance of the contemporary world, an ignorance that sustains us while we live, like medieval lords, on our patrimony. At least for the moment.

Notes

I. Two Decades After Sputnik

1. This point was strongly made by Walter Light, the president and chief executive officer of Northern Telecom in "Technology - Low Man on the National Totem Pole" at the Financial Post Conference on R & D, High Technology: Now or Never, Ottawa, 9 October 1980.

2. Ottawa Citizen, page 49, 11 October 1980.

3. A report prepared by the National Science Foundation and the Department of Education, United States.

4. As an example, at Carleton University, the ratio of undergraduate science to engineering students was 2.43, 1.69 and 0.69 in 1960, 1970, and 1980, respectively.

5. Living and Learning, Report of the Provincial Committee on Aims and Objectives of Education in the Schools of Ontario, Ontario Department of Education, Toronto, 1968.

6. Light, op. cit., p. 2.

7. Ontario Ministry of Education, Curriculum Guideline for the Intermediate Division, Science, Toronto 1978, pp. 46-48.

8. Ibid., pp. 56-62.

9. Ibid., p. 61.

10. The Symons' Report, McClelland and Stewart, Toronto, 1978, or To Know Ourselves, the report of the Commission on Canadian Studies, Volumes I and II, Association of Universities and Colleges of Canada, Ottawa, 1975.

11. James E. Page, A Canadian Context for Science Education, Science Council of Canada, Ottawa, October 1979, p.19.

II Technology, Science and Society

1. Frederick Golden, "Carl Sagan, The Cosmic Explainer," Time, 20 October 1980, p.61.

2. Webster's New International Dictionary, Second Edition.

3. Ibid.

4. A New English Dictionary on Historical Principles, The Clarendon Press, Oxford, 1914.

5. The New Columbia Encyclopedia, Columbia University Press, New York, 1975.

6. Webster's New International Dictionary, Second Edition.

7. Here art, of course, is "skill, dexterity or the power of performing certain actions, acquired by experience, study and observations;..." (Webster's) which is not to be seen as implying that engineers should not also be proficient in the arts (or sciences) of grammar, logic and mathematics.

8. Ontario Council on University Affairs, System Rationalization, Toronto, September 1980, pp. 20-22.

9. James E. Page, A Canadian Context for Science Education, Science Council of Canada, Ottawa, October 1979, p. 13.

10. Ibid., p. 13.

11. Ibid., p. 16.

III Some Options in Science Education

1. John G. Truxal, "Pre-College Classroom Materials" in Engineering Education, January 1980, p. 343.

2. Education Ontario, Ministry of Education and Ministry of Colleges and Universities, Spring 1980, p. 3.

3. Graham W.F. Orpwood and Douglas A. Roberts, "Science and Society: Dimensions of Science Education," in Orbit, volume 11, No. 1, February 1980, pp. 21-25.